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ABSTRACT

Appropriate technology options for sewage management systems are explained in this four-chapter report. The use of appropriate technologies is advocated for its health, environmental, and economic benefits. Chapter 1 presents background information on sewage treatment in the United States and the key issues facing municipal sewage managers. Chapter 2 outlines conventional sewage treatment systems and introduces alternative and innovative technologies. Chapter 3 presents case studies of the experiences of five municipal systems, including the technologies involved, costs, project problems and subsequent solutions, and current status. These projects (funded by the Department of Energy's Appropriate Technology Small Grants Program) focused on vermicomposting, anaerobic primary treatment, digester gas recovery and use, electricity from effluent outfall, and an energy audit/conservation plan. Chapter 4 reviews some of the lessons learned and examines future possibilities. Each chapter includes a glossary and abbreviations list, references/sources, and a list of agencies or individuals able to provide further assistance. A list of selected sewage treatment projects from the Department of Energy Appropriate Technology Small Grants Program is included in an appendix. (ML)

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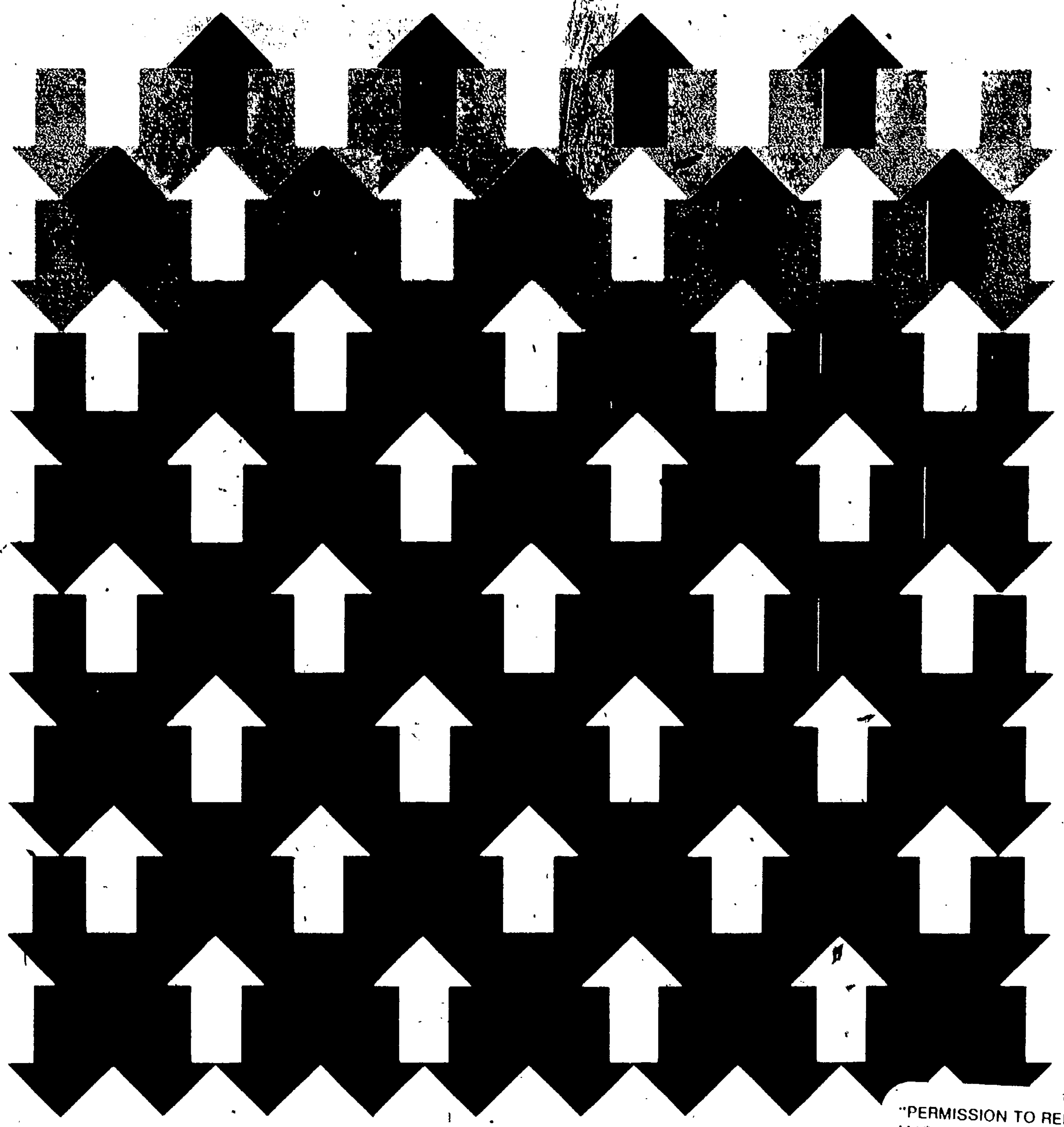
WASTES TO RESOURCES

July 1983

APPROPRIATE TECHNOLOGIES FOR SEWAGE TREATMENT AND CONVERSION



Prepared for:

U.S. Department of Energy
Assistant Secretary, Conservation and Renewable Energy

Small Scale Technology Branch
Appropriate Technology Program
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INTRODUCTION

Managers of municipal sewage systems across the country are confronted with a seemingly contradictory set of challenges. How can they reduce pollution and yet operate within their shrinking city budgets? How can they conserve energy and yet effectively process a growing volume of sewage?

Appropriate technologies have shown that they can provide some of the answers and at the same time help sewage plant managers operate systems more efficiently and with less threat to the environment and human health. And there are other benefits as well. For example, the problem of reducing pollution does not have to be expensive. On the contrary, by using appropriate technologies, money can be saved in the long run by conserving resources through recycling wastes.

More than two dozen projects concerned with wastewater treatment, conversion, or use were funded by the U.S. Department of Energy's Appropriate Technology Small Grants Program. These projects were awarded to individuals and groups as diverse as homeowners, farmers, and the world's largest wastewater treatment plant in Chicago. But all the grantees shared a common concern: that it is simply too expensive, both at the broadest ecological level and at the increasingly critical economic level, to continue wasting materials that are, in fact, resources.

They also shared a common goal of reducing sewage treatment costs. Many cities saved money by implementing appropriate technologies that improve, upgrade, or expand existing systems. Others in the field tested basic new ideas, constructed bench-scale systems, or used appropriate technologies in innovative ways at full-scale. As the various technologies were tested and implemented, two main lessons became clear: significant amounts of the energy and water resources going into sewage collection and treatment can be conserved, and wastes can be converted to resources. Both conservation and waste conversion can save the taxpayers' money, and at the same time can often reduce pollution.

Wastes to Resources: Appropriate Technologies for Sewage Treatment and Conversion is intended to introduce sewage system managers, municipal administrators, and interested professionals and citizens to a general background of appropriate technology options for sewage management. Many of these technologies have shown that they work on existing, traditional sewage systems; others may hold promise for the future.

Chapter One presents background information on sewage treatment in the United States and the key issues facing municipal sewage managers. Chapter Two outlines conventional sewage treatment systems and introduces alternative and innovative technologies.

The case studies in Chapter Three present the experiences of five municipal systems: the technologies involved, the costs, the project problems and subsequent solutions, the energy considerations, and the current status of each project. All five were funded through the U.S. Department of Energy's Appropriate Technology Small Grants Program. (Appendix A lists other projects funded by the Department of Energy under this program.)

Chapter Four reviews some of the lessons learned and future possibilities for the application of appropriate technologies to sewage treatment and conversion. Each chapter includes a glossary and abbreviation list, reference sources, and a list of agencies and people who can provide further assistance.

CHAPTER ONE

SEWAGE COLLECTION AND TREATMENT: THE MAJOR ISSUES

American towns and cities face many broad challenges related to sewage collection and treatment. They have to protect human and environmental health, to maintain or improve water and air quality, and use land, water, and energy effectively. They also have to cope with a maze of local, state, and Federal regulations. And they have to decide how to spend—or not to spend—great sums of money to build and operate sewage systems. Appropriate technologies can be applied to help meet all of these challenges while saving costly energy.

GLOSSARY

Inorganic Compounds: Those compounds lacking carbon but including the carbonates and cyanides: not having organized anatomical structure of animal or vegetable life.

Organic Compounds: Referring to or derived from living organisms. In chemistry, any compound containing life.

Sewage: The waste matter from domestic, commercial, and industrial sources carried by sewers.

Sludge: Mixture of organic and inorganic substances separated from the sewage; generally wastewater with 3 to 8 percent solids.

HEALTH AND POLLUTION

Historically, inadequate sewage handling and treatment has been directly responsible for outbreaks of diseases such as typhoid and cholera. Improved sanitation has largely controlled waterborne diseases in both urban and rural areas. However, modern research has shown that organic and inorganic compounds may cause other long-term health problems such as cancer and genetic defects.

The U.S. Environmental Protection Agency (EPA) lists over 1,000 organic and inorganic compounds that are disposed of in the wastewater of a typical home. More than one hundred of these are known to be potentially dangerous when discharged into surface waters or ground water. Many additional hazardous compounds are part of commercial and industrial wastewaters.

A survey in 1982 for the EPA's Toxic Pollutants Control Program found that a median of only 72 percent of the toxic organic compounds entering municipal sewage works was removed. In many cases, inorganic compounds or viruses pass through sewage works without being separated or treated, and can contaminate surface waters or ground water. Those that are not removed or treated generally are found in sludge. Ammonium and nitrates are often present in the liquid effluent and are of particular concern because they can be harmful to aquatic life.

Studies also indicate that trace metals, such as lead, mercury, cadmium, and zinc often are not removed by sewage treatment plants. High levels of heavy metals are known to cause severe neurological symptoms, chromosome damage, and even death in humans.

WATER AND SOIL CONTAMINATION

About 22 billion gallons of wastewater pass through municipal systems every day. Much of this wastewater eventually reaches drinking water sources.

Together, septic tanks and cesspools are the greatest sources of wastewater discharge into the ground. Also, one-fourth of the municipal treatment systems in the country use some form of wastewater treatment lagoon, and it is estimated that 50 million gallons of wastewater leak from these lagoons every day. An additional 2.3 billion gallons of untreated and treated wastewater are applied daily to the land. If this wastewater is improperly treated or applied, it can pollute drinking water sources or can contaminate the soil with undesirable concentrations of chemicals.

Water pollution can be caused by materials in sewage that inhibit or encourage biological growth. Toxic substances can pollute water and kill both plants and animals. Inorganic materials, such as phosphorus and nitrogen, can over-stimulate plant growth which depletes the water's oxygen and thereby causes massive fish kills.

LAND USE TRADEOFF

Modern, mechanical wastewater treatment plants typically use large amounts of energy and chemicals and relatively little land. Alternative biological wastewater treatment systems generally use small amounts of external energy but require larger amounts of land. In both instances sewage treatment byproducts can be used beneficially on the land.

Today, disturbed land is being reclaimed with sludge, wastewater is being used for irrigation, and sewage treatment is being integrated with other land uses. If all of the nutrients in the country's sewage were recycled and used on the land, it would provide 12 percent of the current demand for commercial nitrogen fertilizers and 20 percent of the demand for phosphorus fertilizers, with a total value of over $1 billion per year.

LAWS AND REGULATIONS

There have been many environmental laws and regulations developed in recent years that apply to sewage systems, most significantly at the Federal level. However, in several cases, such as under the Clean Water Act, the states are encouraged to be active partners. As of January, 1983, 35 states now issue permits and enforce compliance to meet the minimum Federal standards. On the other hand, health and land use related regulations are most often the responsibility of county and municipal authorities.

Major sewage treatment projects face a gamut of regulations, from environmental impact statements to local zoning permits. More frequently, local siting and zoning problems are proving to be the most difficult to overcome because of persistent misconceptions and apprehensions about the nature of sewage treatment. Because so many considerations affect the siting, construction, and operation of sewage treatment facilities, a full survey of environmental and land use factors, and an exhaustive review of regulations which may pertain, are imperative first steps in planning a sewage system.

Early Federal laws recognized that water quality had to be improved, but these were general in nature and did not specify the methods to achieve cleaner water. The Federal Water Pollution Control Act Amendments of 1972 set ambitious goals to restore and maintain the nation's water quality, and it allocated $18 billion (for fiscal years 1973-75) to improve municipal sewage collection and treatment in the country. The emphasis at that time, however, was for municipalities to act quickly to clean up water, which tended to discourage innovation and favor the construction of systems based on standard designs.

FINANCING

The major source of federal funding for municipal sewage collection and treatment facilities is the EPA's Construction Grants Program, authorized by the Clean Water Act. This program provided over $34 billion for the construction or improvement of sewage facilities between 1972 and 1983; states and municipalities contributed an additional $15 billion. The Environmental Protection Agency estimates that, through the year 2000, an additional $70 billion will be needed to construct or improve sewage facilities. In 1982, the Construction Grants Program provided as much as 75 percent of the funds required for construction of sewage facilities, and it provided as much as 85 percent (proposed to be reduced to 75 percent in 1984) of the funding for alternative or innovative treatment systems or components. Funds under this program, which may also cover land costs, are allocated on a priority basis so that the most serious sources of pollution are dealt with first.

The Innovative and Alternative Program was included in the Clean Water Act of 1977 to foster the development and use of technologies that reclaim and re-use water, recycle wastewater constituents, eliminate the discharge of pollutants, or recover energy. By September 1981, 1,035 projects had been funded to use innovative and alternative technologies. These projects have included aquaculture, composting, land application, on-site treatment, and solar applications.

Other Federal programs have been established intermittently, such as the Department of Energy Appropriate Technology Small Grants Program, that provide funds that can be used for sewage treatment projects.

Most states provide some form of financial assistance either through direct grants or loan programs. In many cases, state contributions are inversely proportional to Federal contributions. Federal and state financing rarely combine to pay 100 percent of project costs, although there are situations when funding mixes can meet all costs.

The two traditional sources of local funding are user fees or municipal bonds. The primary limitation with municipal bond issues is the current indebtedness of the community; a city with a significant debt will probably be unable to issue bonds. Recently, some districts have used tax-free, industrial development bonds to finance projects.

A number of alternative financing options are being developed for municipalities, many of them involving the cooperation of cities and local businesses. This may be particularly appropriate if it is necessary to pretreat industrial wastes entering the municipal system. With the significant capital outlay required for sewage facility construction, operation, and maintenance, every financing option should be explored.

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CHAPTER TWO

SEWAGE MANAGEMENT, TREATMENT, CONVERSION, USE, AND DISPOSAL

Knowing which appropriate technologies can be used to solve sewage treatment problems requires an understanding of present practices. Conventional systems and alternatives already in use provide the context for appropriate technology applications. In this chapter, an array of existing technologies is briefly introduced and reviewed.

GLOSSARY

Aerobic:
Life or biological processes that can occur only in the presence of oxygen.

Anaerobic:
Life or biological processes that occur in the absence of oxygen.

BOD:
Biochemical oxygen demand.

Centralized Sewage Treatment:
The collection and treatment of sewage from many sources to separate pollutants and pathogens from the wastewater.

Effluent:
The treated wastewater discharged by sewage treatment plants.

Evapotranspiration:
The water released from plants as they grow and the evaporation of water from plant surfaces and adjacent soil.

Facultative Ponds:
Ponds having an aerobic zone on the top and an anaerobic zone on the bottom.

Infiltration:
Leakage of ground water through poor joints, etc. into the sewage collection system.

Influent:
Wastewater going into the sewage treatment plant.

MGD:
Million gallons per day.

Percolation:
The filtering of a liquid passed through a medium with many fine spaces.

Polishing Treatment:
The final sewage treatment process to further reduce BOD_5, SS, and other pollutants.

Recirculation:
Returning a fraction of the effluent outflow to the inlet to dilute incoming wastewater.

SS:
Suspended Solids.

TREATMENT SYSTEMS

Conventional Centralized Plants

Most of the urban centers in the United States are served by conventional treatment plants which use mechanical and chemical processes to break down and treat sewage. Most of these plants incorporate four basic stages: preliminary, primary, secondary, and advanced (see Figure 2.1). Wastewater treatment is usually concluded with disinfection of the effluent, most often by chlorination.

Lagoons

Lagoons require large amounts of land and are best suited to warm and moderate climates. However, lagoons continue to be a useful alternative, particularly for smaller communities, because of the low construction costs and minimal operating requirements. Lagoons generally do not treat wastewater as effectively as conventional plants, but they can be used in many parts of the country, because systems with low flow rates are permitted to release higher levels of suspended solids than larger systems. Odor and mosquitoes are common problems with lagoons, and the nutrients and minerals that settle to the bottom are rarely reclaimed. There are generally three types of lagoons that are used for all levels of treatment: anaerobic, aerobic, and facultative.

Anaerobic lagoons are relatively deep, with minimal dissolved oxygen except at the surface. Levels of BOD_5 and SS are commonly reduced by 50 to 70 percent.

Aerobic lagoons are generally less than 2-feet deep and use the action of wind, sunlight, and algae to convert wastes. While treatment efficiencies can be very high, the algae that convert the wastes can create higher BOD_5 and SS conditions than the wastewater had originally. To achieve maximum results, lagoons must be deeper and use mechanical aeration, which consumes large amounts of energy.

Facultative lagoons have an aerobic zone on top and an anaerobic zone on the bottom. This requires depths of about 12 feet at the inlet to as little as 3 feet at the outlet. Either a preliminary treatment stage or recirculation is required to keep the surface zone aerobic. Sludge build-up in well-managed facultative ponds is relatively low, and a trench at the entrance end can be used to accumulate the sludge that is produced (see Figure 2.2).

Aquaculture

Aquaculture treatment of sewage began to develop when hyacinths were added to traditional lagoons to produce cleaner water and reduce odors. Water hyacinths are most commonly used to treat wastewater, but aquaculture systems can also use other aquatic plants, animals, or both.

If water hyacinths are used to treat wastewater from facultative ponds, they are capable of producing very clean effluent. Hyacinth ponds alone can be very effective in

Sewage treatment performance is commonly measured in terms of biochemical oxygen demand, suspended solids, and phosphorus.

The amount of oxygen needed by bacteria and other microorganisms to oxidize organics for food and energy is called **biochemical oxygen demand** (BOD). Biochemical oxygen demand is a process that occurs over a period of time, and it is commonly measured for a five-day period, referred to as BOD_5. Biochemical oxygen demand is an important water quality measurement, because the type of aquatic life is determined by the amount of oxygen in the water.

Waste particles suspended in water, referred to as **suspended solids** (SS), can harbor harmful microorganisms and toxic chemicals. Suspended solids cloud the water and make disinfection more difficult and costly.

Phosphorus (P), in its inorganic forms is necessary at some levels, but when it is concentrated it becomes a pollutant that can overload ecosystems beyond their capacity to assimilate it. This not only upsets the biological balance, but also diminishes the natural capacity of the environment to break down and use wastes.

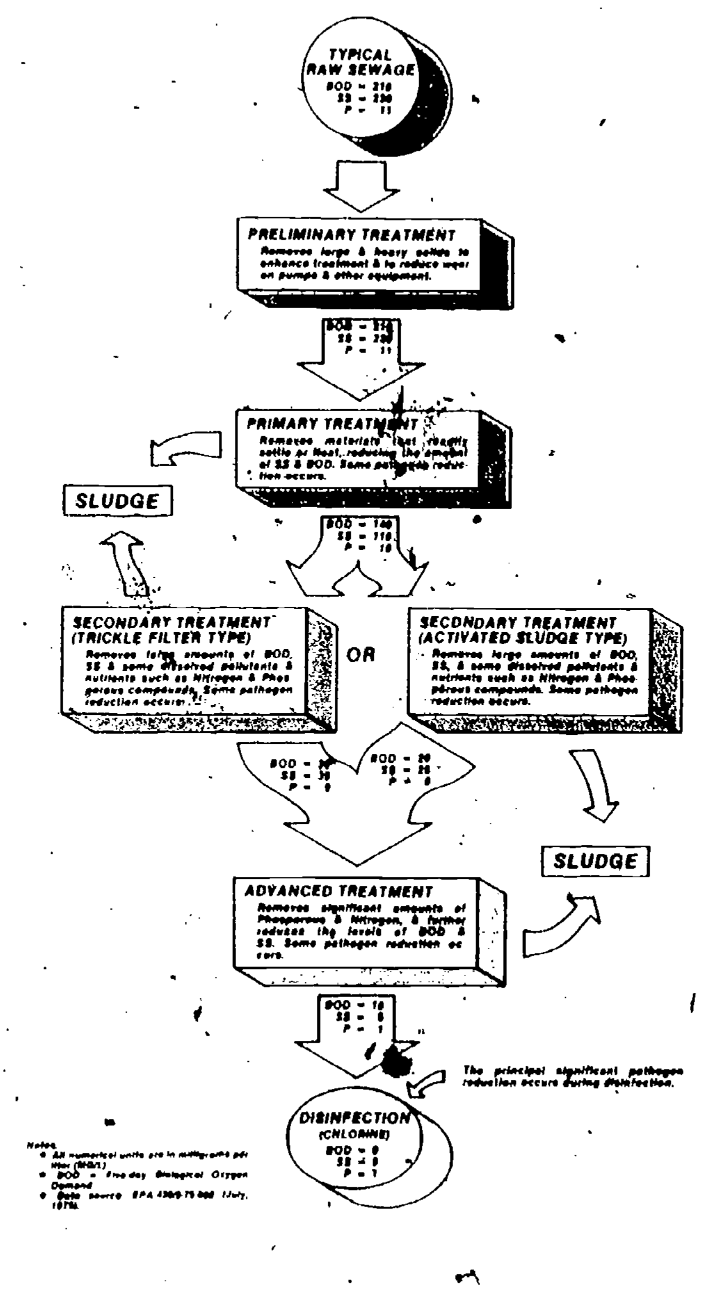

Figure 2.1 Measuring Sewage Treatment Performance

treating wastewater if recirculation is used. Hyacinth ponds are 2- to 3-feet deep and typically require 5 to 15 acres per million gallons per day to achieve secondary to advanced treatment water quality (see Figure 2.3). Ponds are primarily aerobic, and about one-fifth of the surface is kept cleared of plants to help maintain aerobic conditions at the surface. Water hyacinths can be harvested for use as a fertilizer and soil conditioner, or as an animal feed supplement. Hyacinths and sludge also make an ideal compost mixture.

Full-scale hyacinth treatment systems are now operating in Texas, Florida, and Mississippi. The largest hyacinth pond system in the country is being planned for Stockton, California.

Hyacinth ponds are used today only in warm climates because the plants die when exposed to freezing temperatures (see Figure 2.4). Duckweed, watercress, and cattails are used in cooler climates. In cold regions, other plants that normally tolerate colder weather, such as European iris, or new genetic strains of plants may provide alternatives. Mosquitoes can be a problem with all lagoon systems, but they can be controlled if fish are added to aquaculture treatment systems.

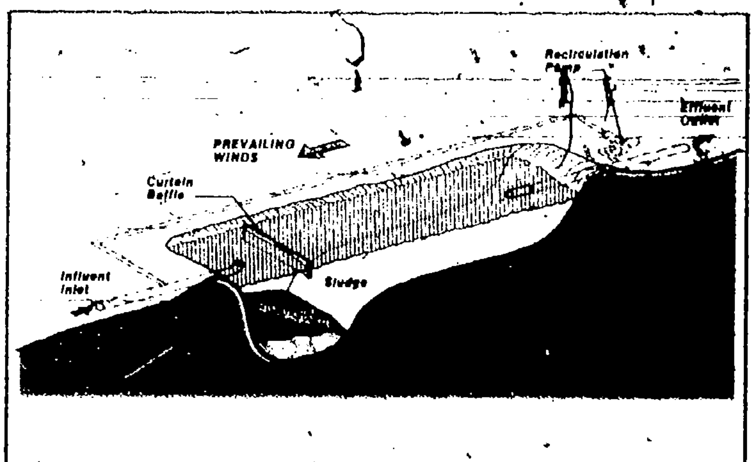

Figure 2.2 Typical Facultative Lagoon

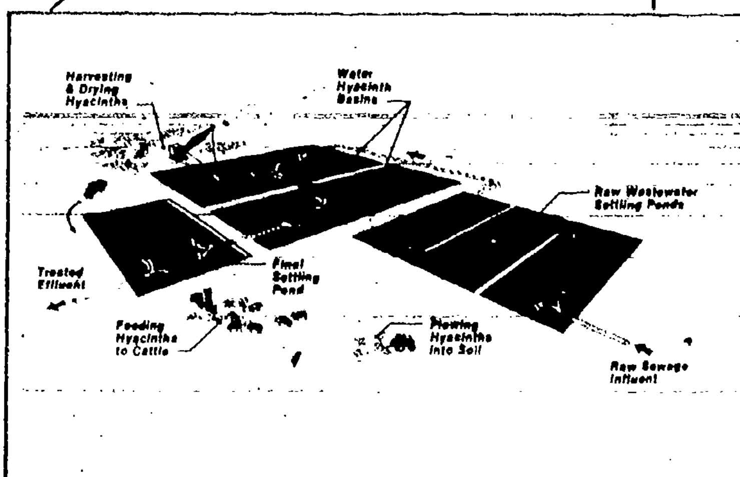

Figure 2.3 Water Hyacinth Treatment Basins

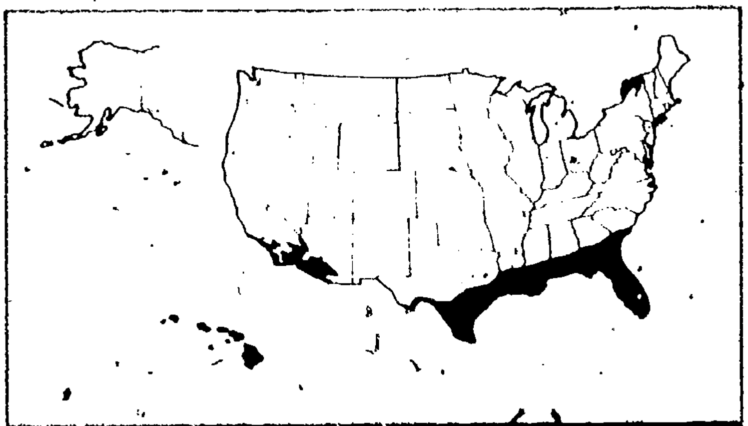

Figure 2.4 Shaded Areas Are Best For Hyacinth Use

Land Treatment

Wastewater and sludge are treated by land application in about 1,200 locations in the United States. If properly handled, land treatment can be more effective than conventional secondary treatment, and operation and maintenance costs are usually low. It requires larger areas of land than conventional plants, but it is well-suited to small community needs, especially in agricultural areas. Three main land application techniques are used: slow-rate, rapid infiltration, and overland flow. The suitability and effectiveness of these techniques depend on the availability of land with the proper characteristics (see Table 2.1) When trace metals are a problem, lime or other pH adjusters must be applied to stabilize those metals on acidic soils. Consequently, operating costs are generally lower with alkaline soils.

Slow-rate is the most popular and reliable land treatment method (see Figure 2.5). Primary treatment is required to remove solids that might clog the equipment and reduce BOD_5 levels to control odor problems. The sewage is treated when the vegetation absorbs and uses the sewage nutrients and water. What isn't absorbed by the plants either evaporates or percolates through the soil.

With **rapid infiltration**, wastewater is spread in porous basins and treatment occurs in the soil (see Figure 2.6). Wastewater usually receives primary treatment to reduce solids and BOD_5. Nitrogen and salt build-up in the soil may be limiting factors to this and other land treatment methods. A build-up of nitrogen can increase the concentration of nitrates, which are easily leached out of the soil, and can contaminate ground water. High salt levels restrict the ability of plants to take up water and nutrients.

With **overland flow**, wastewater is applied upslope and allowed to flow downhill through vegetated surfaces to runoff collection ditches and into lagoon basins (see Figure 2.7). Preapplication treatment is normally used to remove grease and some solids. Overland flow is an excellent polishing treatment if it follows conventional secondary treatment.

In a variation of land application treatment, **wetlands** can be used to treat wastewater in areas where the water table is at the surface. Wastewater is treated by the biological processes of a complex ecosystem, as well as by evapotranspiration and percolation. Wetland systems can achieve higher removal efficiencies than mechanical systems. Natural wetlands, such as marshes and swamps, or artificial wetlands have been used to treat both raw and treated wastewater (see Figure 2.8).

Characteristics	Application Method		
	Slow-Rate	**Rapid Infiltration**	**Overland Flow**
Slope	Less than 20% on cultivated land: less than 40% on non-cultivated land.	Not critical: excessive slopes require much earthwork.	Slopes of 2 to 8%.
Soil Permeability	Moderately slow to moderately rapid.	Rapid (sands, loamy sands).	Slow (clays, silts, and soils with impermeable barriers).
Depth to Ground Water	2 ft to 3 ft (minimum).	10 ft (lesser depths are acceptable where underdrainage is provided).	Not critical.
Climatic Restrictions	Storage often needed for cold weather and precipitation.	None (possibly modify operation in cold weather).	Storage often needed for cold weather.
Land Area per MGD	57 to 560 ac	2 to 57 ac	16 to 111 ac

Source: *Operation and Maintenance Considerations for Land Treatment Systems*, EPA 600/2-82-039, NTIS, Springfield, VA, June 1982.

TABLE 2.1 COMPARATIVE SITE CHARACTERISTICS FOR LAND TREATMENT PROCESSES

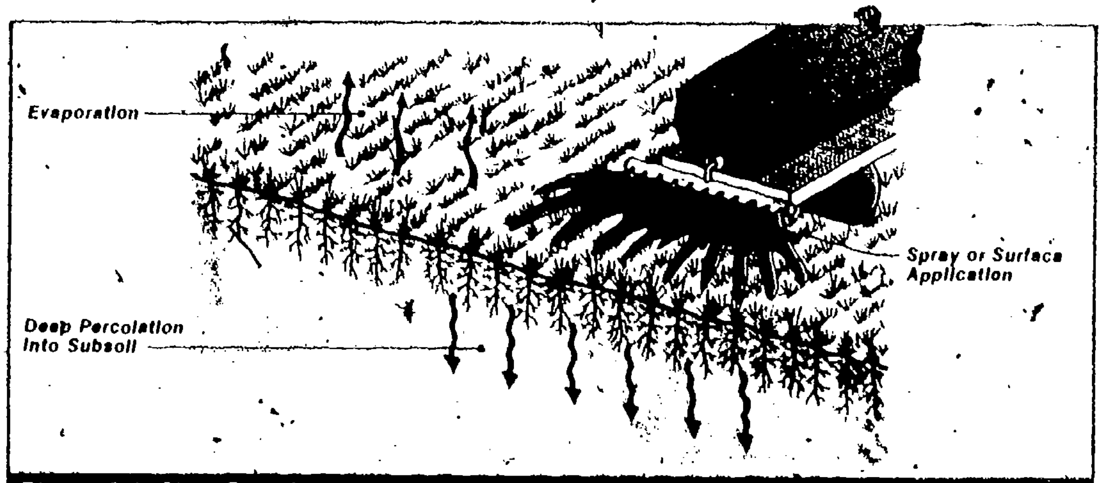

Figure 2.5 Slow-Rate Land Application

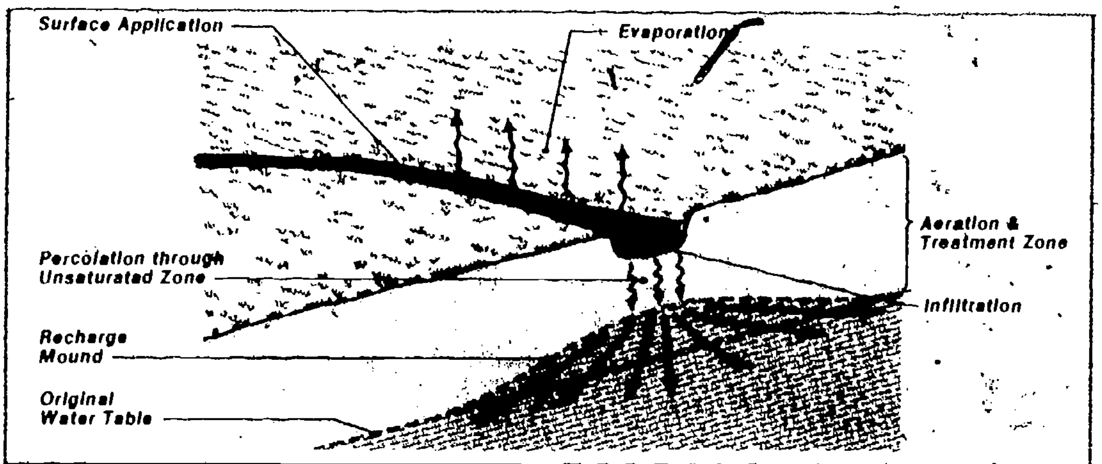

Figure 2.6 Rapid Infiltration Land Application

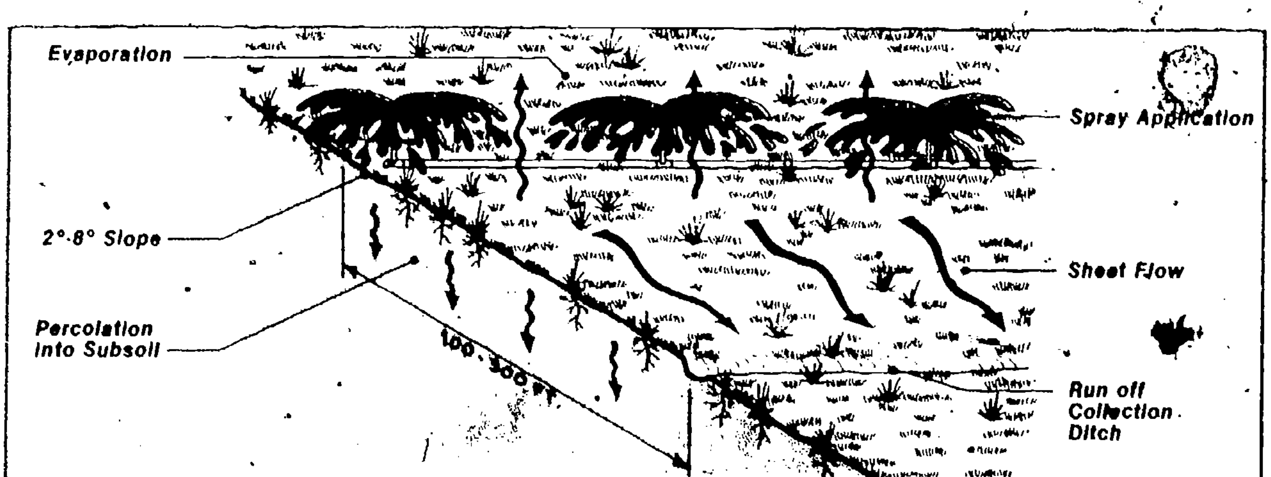

Figure 2.7 Overland Flow Land Application

Figure 2.8 Typical Artificial Wetland

MANAGEMENT AND USE OF SLUDGE

With most sewage treatment systems, two products result: liquid effluent and sludge. Suitably treated, liquid effluent may be discharged into surface water bodies, injected into the ground, or re-used for irrigation or industrial process water. In the same way that appropriate technology can provide alternatives to conventional sewage-treatment processes, it can also offer alternative options for the use of sludge.

Sludge is composed of 3 to 10 percent organic and inorganic solids; the rest is water. In the United States, more than half of the sludge produced is disposed of in landfills or by land application (see Figure 2.9).

Methane is produced naturally from the breakdown of sludge buried in landfills, and this resource can be recovered. Instead of allowing the gas to rise to the surface and escape, wells are drilled into the landfill, and the gas is collected and processed for use or sale (see Figure 2.10). Proper planning and management of the landfill can increase the amount of gas produced and recovered.

Much of the work currently being done to improve the handling, use and disposal of sludge involves improvements to existing techniques, such as the recovery and use of heat from incineration. The appropriate technologies that are most commonly applied in sludge management include land application, solar drying, and composting.

Land Application. Sludge, which can be a source of valuable soil nutrients, can be applied to the land dried, as compost, or as a liquid. Properly treated, it is possible to recycle the nutrients inherent in sludge with minimal health risks.

Solar Sludge Drying. The natural heat of the sun is routinely used to dry sludge on sand beds throughout the country. Studies continue to explore the applications of active and passive solar sludge drying techniques. Experiments with passive solar sludge drying at the Los Alamos National Laboratory have produced a method for estimating the performance of indoor and outdoor passive solar sludge drying. Tests indicate that passive solar drying inside sunspaces is more effective in climates with high rainfall.

Composting is an effective way to decrease the pathogen density of sewage sludge and return the nutrients to the land. As of 1982, composting was classified as an alternative sludge management system by EPA and became eligible for 85 percent Federal funding under the Construction Grants Program. Sludge composting is now practiced from the hot and humid climate of Puerto Rico to the severe cold of Bangor, Maine.

Three sewage sludge composting methods are most common: windrow, static aerated pile (see Figure 2.11), and within-vessel. All three methods provide "significant" and "further" levels of pathogen reduction, although the periodic turning of windrows can contaminate composted material with uncomposted material. Windrow and static aerated pile methods were developed in the United States and Canada, and have proven to be cost-effective, environmentally acceptable options. The within-vessel method was developed in Europe and is used there successfully.

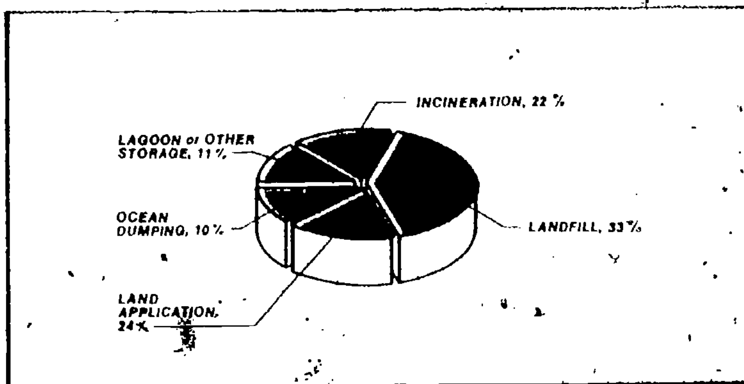

Figure 2.9 Sludge Disposal Methods

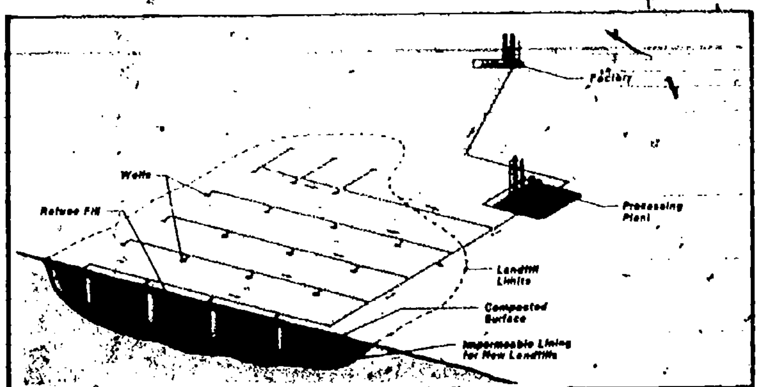

Figure 2.10 Landfill Methane Recovery

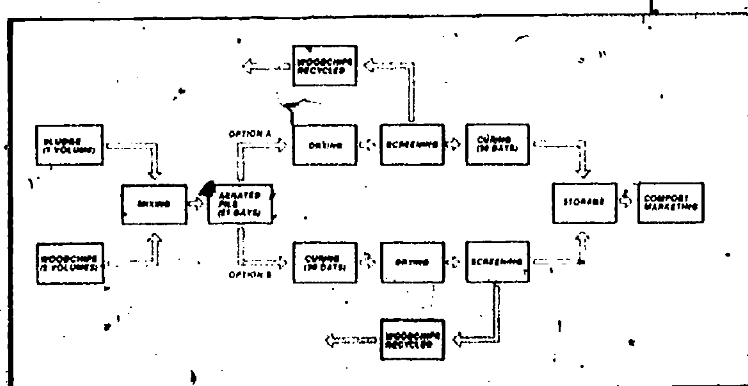

Figure 2.11 Static Aerated Pile Composting Process

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SYSTEM-WIDE MANAGEMENT STRATEGIES

Water shortages in some parts of the country, coupled with general concern about the continuing demand for water, have required a closer examination of water use and the potential for conservation.

Studies indicate that conservation could reduce water consumption by as much as 40 percent. If overall water use were reduced by even 10 percent, there would be an appreciable effect on water supply and wastewater treatment systems. For example, if a sewage system originally designed for 12.5 MGD were redesigned for a 10 percent reduction in influent, annual costs would be reduced by about $4.3 million per year for the life of the plant. When less water is used, the water supply system pumps and treats less water, uses less energy, and saves money. Consequently, it also takes less energy to pump and treat wastewater (see Figure 2.12).

Although there are significant net energy savings as a result of water conservation, there can be incremental increases in energy and chemical costs to treat sewage that is more concentrated. Increased odor can also be a problem in both collection and treatment systems. In practice, the problems resulting from lower water levels have been successfully resolved with modified operation and maintenance.

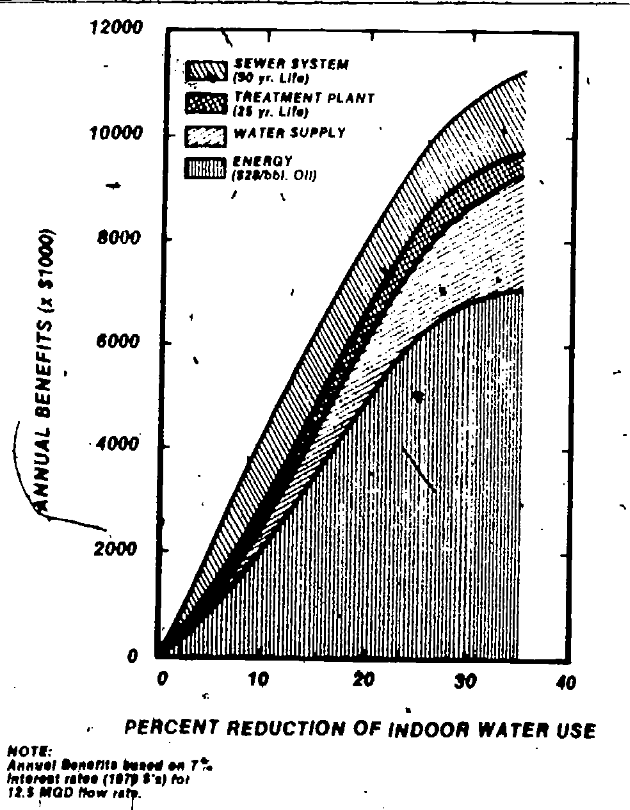

Figure 2.12 Annual Water Conservation Benefits

Many of the problems associated with reduced sewage loads occur because conservation plans are implemented after sewage treatment plants have been designed and built for larger loads. If water conservation plans were established and accurate load estimates were developed prior to construction, then collection and treatment systems could be planned that would avoid the problems and maximize the benefits. Lower construction costs for collector systems and treatment plants, and lower energy demand and reduced costs for pumping have been realized in all parts of the country as a result of such efforts.

Decentralized Systems

The general perception is that nearly all of the United States is served by systems that collect sewage from broad areas and transport it, by sewer collection systems, to a central treatment plant. While these centralized systems clearly predominate, about 30 percent of the United States population uses decentralized disposal systems. Recent population shifts from urban to suburban and rural areas have placed an increasing number of people in areas where centralized systems are impossible, impractical, or unaffordable. On-site waste disposal systems offer several alternatives.

Three types of on-site waste disposal systems are most common: septic tanks, cesspools, and privies. Several more advanced systems are now available, such as composting toilets, incinerating toilets, recirculating toilets, chemical toilets, aerobic systems, vacuum systems, and evapotranspiration.

Recently there has been increasing interest in using on-site disposal methods more systematically. Case studies indicate that on-site disposal systems, developed on a community basis, benefit greatly from the establishment of their own waste management organization.

Community waste management organizations, set up by municipalities, developers, or homeowners, provide several benefits. They can have preliminary studies performed, establish construction and operation standards, monitor construction, provide personnel to monitor operations, and provide maintenance and service. The greatest benefit is that they can provide the advantages of a well-run decentralized system, without requiring the individual property owner to become a sanitation engineer.

Such systems can also have lower capital costs and provide more jobs than large, central systems.

As with any new undertaking, there are drawbacks to decentralization that must be considered. To form and operate a decentralized waste treatment organization requires more involvement by the individual than it does to hook into an existing central system. In addition, site characteristics or state and local regulations in some areas may prohibit the use of certain systems. While these problems are not insurmountable, they must be realistically evaluated.

On-site evapotranspiration systems normally consist of a bed of gravel, sand, and soil containing a distribution piping system, underlaid by an impermeable liner (see Figure 2.13). Wastewater is pretreated by grease traps and either a septic tank or an aerobic treatment system. The surface of outdoor evapotranspiration beds is sloped to drain off rain water and is planted with vegetation. The liner prevents the wastewater from draining into the soil, and water is raised to the upper portion of the bed by capillary action in the sand where it evaporates into the air. Also, vegetation transports water from the root zone to the leaves (and stems of some plants), where it is transpired.

Climatic conditions are the most significant constraint to the use of evapotranspiration systems. Year-round, non-discharging outdoor systems are practical only in arid and semi-arid portions of the western and southwestern United States. Indoor evapotranspiration systems under transparent covers and in greenhouses have been proposed to extend their use to other regions. Covered beds can be smaller because the bed does not have to evaporate or transpire the added water of rainfall.

Evapotranspiration systems in attached solar greenhouses can be used to process domestic greywater. In addition, non-food plants grown using the wastewater nutrients have the ability to absorb air impurities through their leaves while absorbing water pollutants through their roots. Therefore, a fully-integrated greenhouse and evapotranspiration system can treat and dispose of domestic wastewater, remove indoor air pollutants, such as formaldehyde, and provide space heating for the attached building.

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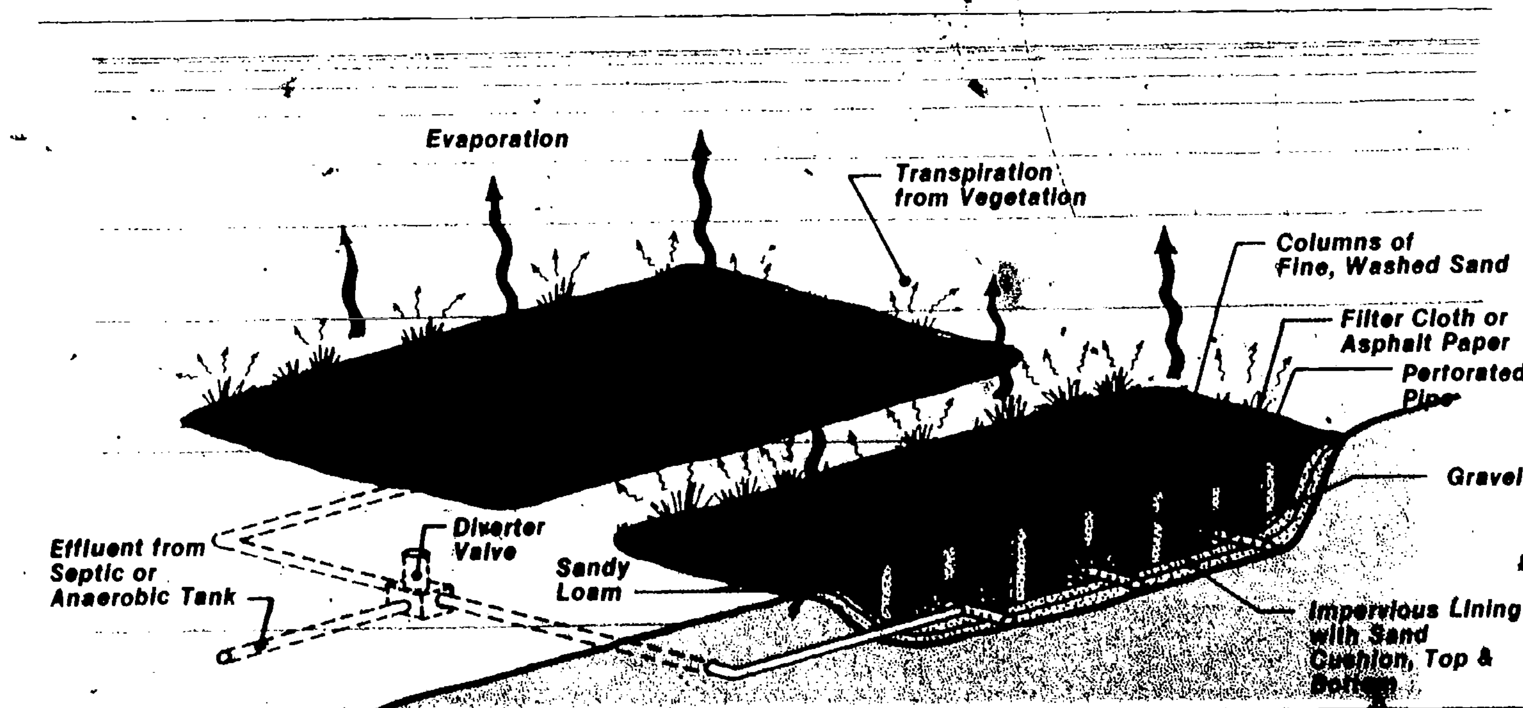

Figure 2.13 [illegible]

CHAPTER THREE

CASE STUDIES: APPROPRIATE TECHNOLOGY AT WORK

More than a dozen cities, towns, and individuals across the country were able to develop appropriate technology solutions to municipal sewage problems with grants from the U.S. Department of Energy Appropriate Technology Small Grants Program.

The projects examined in this chapter were selected as examples of the range of technologies employed and the range of project sizes. These grantees managed existing systems more effectively, modified existing systems to reclaim the energy from methane and effluent that had been wasted, and tested the effectiveness of new processes for sewage treatment.

These projects were also chosen because they were associated with established sewage treatment plants, with capacities that range from moderate to the largest in the world. This makes the lessons learned more useful to managers of other similar treatment systems. Finally, these projects were selected because they have had enough time to prove themselves. The case studies in this chapter have been prepared from project final reports (available from the National Center for Appropriate Technology), and follow-up contacts with the grantees.

Experimental science rarely yields overnight successes. All of the case studies reviewed here have achieved substantial results, but there are other projects sponsored by the Appropriate Technology Small Grants Program that also contributed to the knowledge of sewage treatment through their work (see Appendix A). While most of the projects deal directly with municipal sewage treatment, some deal with other technologies, such as on-site treatment systems, that can affect municipal systems.

GLOSSARY

Activated Sludge Process:
A biological wastewater treatment process in which a mixture of wastewater and activated sludge is agitated and aerated. The activated sludge is subsequently separated from the treated wastewater by sedimentation and disposed of or returned to the process as needed.

Aeration Basin:
A basin where oxygen is supplied by mechanical agitation or pneumatic means to enhance the breakdown of wastes held in suspension.

Bar Screen:
A screen made of parallel bars from about three-quarters of an inch to two inches apart, used to filter out large objects.

Cascade Aeration:
Aeration of the effluent stream through the action of falling water.

cfm:
Cubic feet per minute.

Clarifier:
A tank used to remove settleable solids by gravity, or colloidal solids by coagulation, sometimes following chemical flocculation; will also remove floating oil and scum through skimming.

COD:
Chemical oxygen demand. A measure of the oxygen equivalent of that portion of organic matter that is susceptible to oxidation by a strong chemical oxidizing agent.

Coliform Bacteria:
A bacteria whose presence in wastewater is an indicator of pollution and of potentially dangerous contamination.

DC:
Direct current.

Deaeration:
Removal of gases from a liquid.

Flow Rate:
The amount of water that moves through an area (usually pipe) over a set period of time.

Francis Turbine:
A water-powered turbine used to transform water falling vertically to mechanical (rotating) energy.

gal/d:
gallons per day.

Head:
The vertical distance water drops from the highest level to the level of the receiving body of water.

Header:
A pipe from which two or more tributary pipes run.

hp:
Horsepower.

Hydraulic Load:
Amount of liquid going into the system.

Imhoff Treatment System:
A tank without aeration or oxygenation where solids settle out of the wastewater and may be digested in a separate compartment in the bottom.

Induction Generator:
A variable speed multi-pole electric generator which is simple, rugged, reliable, and relatively inexpensive.

Inflow:
Water (and pollutants) that enter sewage systems through street inlets, roof drains, and similar sources.

kW:
Kilowatt.

kWh:
Kilowatt-hour.

Mesophilic:
An optimum temperature of 25-40°C, for bacterial growth in an enclosed digester.

MGD:
Million gallons per day.

mg/l:
Milligrams per liter.

mscf:
Thousand standard cubic feet.

Mscf:
Million standard cubic feet.

NTU:
Nephilometric turbidity unit. A measurement unit of the clarity of water, dependent on the amount of suspended matter.

PCB's:
Polychlorinated biphenyls, a group of organic compounds. PCB's are highly toxic to aquatic life; they persist in the environment for long periods of time, and they are biologically accumulative.

pH:
A measure of the acidity or alkalinity of a substance (7.0 is neutral).

Post-Aeration:
The introduction of oxygen into wastewater after secondary or advanced treatment to further reduce BOD and COD.

Pilot Scale:
The size of a system between the small laboratory model size and a full size system.

psig:
Pounds per square inch gage pressure.

Therm:
A unit of heat equal to 100,000 British thermal units.

Walterboro, South Carolina Wastewater Treatment Plant

As part of its overall effort to control municipal costs, the City of Walterboro used a $6,500 grant to evaluate the operation of the Wastewater Treatment Plant and to identify ways to reduce electrical consumption. The study had two primary goals: compare how the plant was designed with how it was actually operating, and then find out what could be done to cut electricity use and costs. All treatment units at the plant were considered:

- Bar Screen
- Grit Removal
- Influent Pumping
- Aeration Basin
- Clarifier and Sludge Recirculation
- Post-Aeration

It should be noted that prior to this study, energy use at the plant had been reduced by a sizeable 30 percent through the modification of existing operating procedures. Lighting and heating loads were not considered in this energy study; because they were known to be relatively small and well managed.

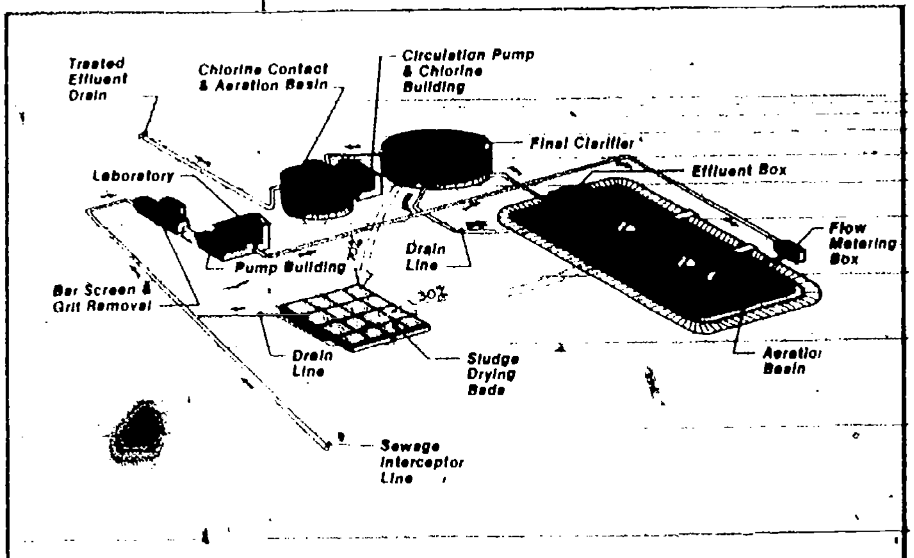

Figure 3.1 Walterboro Wastewater Treatment Plant

Technological Processes and Operation

In 1972, the Walterboro treatment plant was upgraded. However, because of low energy costs at that time, energy efficiency was not a design consideration, and the upgrade included oversized units that energy auditors found to be unnecessary for effective and efficient plant operation.

The audit found that organic levels at the plant were lower than expected and the water volume was higher than expected. Organic loading was lower because pretreatment (of slaughterhouse wastes) had decreased the volume of organics, and inflow and infiltration into the collection system were diluting the organic load and increasing the hydraulic load. Plant flow rates averaged between 1.25 MGD and 2.5 MGD, but during rainy periods daily flows peaked as high as 6.0 MGD. The average flow of sewage into the system was only .65 MGD; the rest was water from inflow and infiltration. Consequently, sewage at the plant was fairly weak, averaging 110 mg/l BOD_5 and 110 mg/l for SS. A sewer rehabilitation program is expected to reduce inflow during rainy periods, but the average flow rate is expected to continue in the 1.25 MGD to 2.0 MGD range.

Screening and Grit Removal. The study determined that operating the bar screen on a timer for 12 to 14 hours per day, rather than around-the-clock, could result in a 40 percent energy savings for this part of the process. This change would have a high return on investment, but the overall impact would be fairly minor, because screening and grit removal accounted for only 0.6 percent of total electrical demand for the plant. It is also possible that timed operation could increase grit compaction in the housing for the bar screen lower bearings. Therefore, this measure was given a low priority.

Influent Pumping. The influent pumping station at the plant has two 100-hp main pumps and a 15-hp back-up pump. By design, only one main pump could operate at a time, and it usually operated at only 15 to 40 percent capacity. (The pump occasionally operated at full capacity during periods of extraordinary inflow.) So much excess capacity made the influent pumps the most inefficient plant operation. The study found that three modifications in the pumps would be effective: 1) to install a new, 30-hp pump that would be turned on manually to handle normal flows; 2) rebuild and reduce the capacity of one main pump to 50 hp for normal flows and some peak flows, and 3) reduce the capacity of the other main pump to 75 hp for peak flows. It was estimated that implementation of these modifications would reduce consumption for influent pumping by 43,000 kWh per year.

Aeration Basin. The volume of the aeration basin is 1.85 million gallons. It was

found to be organically underloaded, and either of the two 100-hp, low-speed aerators could maintain satisfactory oxygen levels and solids suspension. If the normal organic loading rate were doubled, it was estimated that 120 hp would be required to maintain required oxygen levels. The study indicated that the most effective way to do this would be to replace one of the 100-hp aerators with up to three 20-hp, floating aerators. This step would result in a 40 kVA demand reduction. Even with no changes in the aerator configuration, as much as 36,000 kWh per year could be saved by purchasing a dissolved oxygen meter, monitoring oxygen levels in the basin, and operating the aerators to meet specific oxygen demand. Some savings have already resulted from changing the schedules for operating the fixed aerators.

Clarifier. Before the study, a trickling filter was converted to a 7-foot deep clarifier, about half the depth of normal clarifiers. This clarifier unit and the sludge recirculation pumps use more energy than deeper clarifiers, and accounted for about 15 percent of the plant power requirements. Both the clarifier sweep and the recirculation pumps ran most of the time. It was determined that these could be run less if solids from the aeration basin were reduced and the recirculation rate for the pumps were lowered. Also, pump performance could be increased by changing pump pulleys; one pump should handle low-flow operations. Modification of the inlet structure to reduce flow restriction has reduced the energy needed for pumping.

Post-Aeration. Chlorination is followed by mechanical post-aeration in a converted clarifier tank. Effluent from the tank is discharged to a canal with a drop of 20 feet, which was estimated to be sufficient to provide post-aeration to meet permit standards. Replacing the mechanical aerator with this cascade aeration would totally eliminate the power demand for post-aeration.

Energy and Economics

At the time of the audit, energy consumption at the Walterboro Plant averaged 71,300 kWh per month. If all of the efficiency changes proposed by the energy audit were made, electric consumption would be reduced an average of 11,468 kWh per month, a reduction of 16 percent. The potential for energy savings for individual components range from 7.5 percent (operating the aeration basin based on measured oxygen levels) to 100 percent, if cascade aeration replaced the post-aeration tank (see Table 3.1). These changes would also offer a range of cost savings and payback periods.

Proposed Alteration	Energy Savings (Percent)	Cost Savings ($/Year)	Payback (Years)
Bar Screen			
Operate Bar Screen on Timer	40.0%	$ 37	1.4
Influent Pumping			
Modify Influent Pump & Add Pump	22.0%	$2,200	11.4
Aeration Basin			
Option 1 Replace One Fixed Aerator with Three Floating Aerators	12.5%	$3,840	5.9
or Option 2 Monitor Oxygen Levels in Aeration Basin	7.5%	$1,836	.8
Clarifier			
Reduce Solids to Clarifier and Run One Pump	12.0%	$ 744	.3
Post-Aeration			
Option 1 Operate Post-Aerator on Timer	62.0%	$ 612	4.9
or Option 2 Replace with Cascade Aeration	100.0%	$ 984	15.2

TABLE 3.1: PREDICTED ENERGY SAVINGS AND COST REDUCTIONS

Highlights and Current Status

Operators at the Walterboro Wastewater Treatment Plant have learned how to take control of energy consumption. They now understand the plant in terms of energy performance and the relationship between how things were designed and how they actually work. Changes in operating procedures (mostly by using timers) put into effect before and as a result of the audit have already achieved significant savings. As the city budget will allow, Walterboro operators can implement further cost saving steps that require larger capital investments.

This case illustrates what to expect from energy conservation programs at sewage treatment facilities. The savings overall are in the 15 percent range. That may not seem like much, but sewage treatment is a fixed cost for all communities in the United States. Residents pay year after year, and rising energy costs are increasing the burden on municipal budgets. Shaving 15 percent from the cost of a perennial community service is an important contribution, especially on top of the 30 percent savings Walterboro had achieved before the study.

WHO TO CONTACT:

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City of Walterboro
P.O. Box 717
Walterboro, S.C. 29488
Telephone (803) 549-2545
Final Report: NCAT ID #SC-81-006
DOE Contract No.: DE-FG44-81R410422

Several recent publications are available that provide detailed suggestions and methods for conserving energy at wastewater treatment plants.

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WHERE TO FIND MORE INFORMATION

DIGESTER GAS RECOVERY AND USE

Metropolitan Sanitary District of Chicago, Illinois

The West-Southwest Sewage Treatment Works, just west of Chicago, is the world's largest. In an average day, it treats about 800 million gallons of sewage. Sludge treatment generates approximately 2.7 Mscf of gas per day. Before this project was initiated in March 1980, 1.7 Mscf of gas was burned to maintain mesophilic operating temperatures in the digesters—1.0 Mscf was flared off as waste gas. Sanitary District personnel designed and implemented a system to make better use of the gas produced by sludge digestion with a $50,000 grant from the Department of Energy and a $780,000 investment of its own.

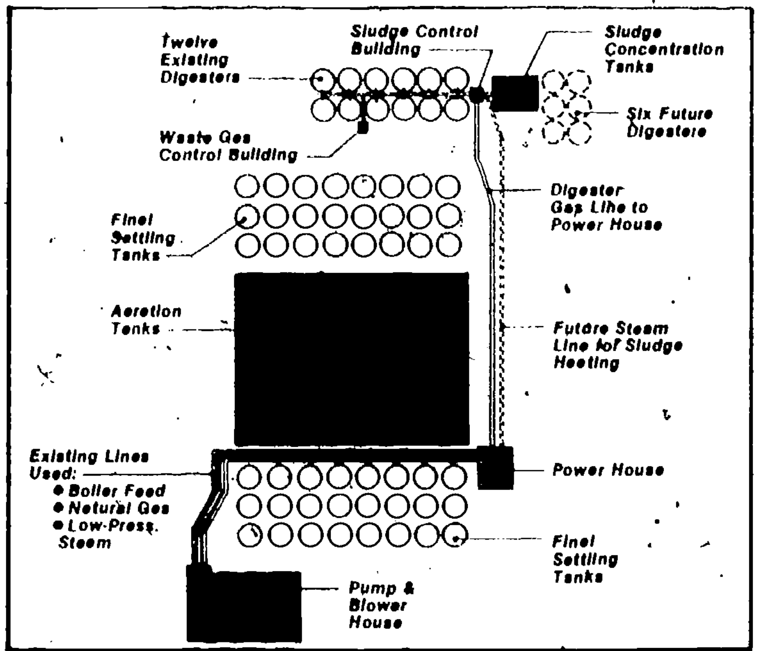

Figure 3.2 West Southwest Sewage Treatment Works

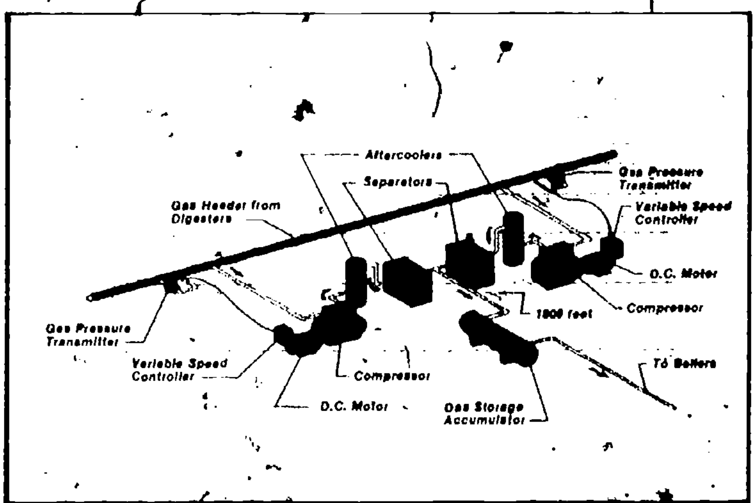

Figure 3.3 West Southwest Sewage Treatment Works

Modesto, California has been running seven city vehicles on methane from its wastewater treatment plant since 1978. The pilot project has been so successful that city managers have planned a full-scale operation for 1983 that will serve about 200 vehicles.

One key to the Modesto success has been the cleaning process that yields gas that is 98 percent methane. City vehicles were converted to use either gasoline or methane at a cost of about $1,200 per vehicle.

Methane from the pilot project was estimated to cost about 35 cents for the equivalent of a gallon of gasoline. The vehicles have performed well using the methane, which burns cleaner than gasoline and seems to cause less engine wear. Only the police had any complaints; they felt methane didn't fuel their cars with quite as much "punch" as gasoline.

SEWAGE GAS POWERS CARS & TRUCKS

Technological Processes and Operation

The West-Southwest Works uses the activated sludge process and incorporates two separate sludge digestion systems: an Imhoff treatment system and a heated anaerobic digestion system. Only the heated anaerobic digestion system is included in the gas gathering process. There are currently 12 high-rate digestion units, each with a 2.5 million gallon capacity, operating at the plant. [Six additional digesters are proposed, each with a 3.0 million gallon capacity (see Figure 3.2).]

After an engineering study was completed, a gas-collector-and-boiler system was constructed. In the new system, gas is collected from the digesters, compressed, cooled and dried, and then piped about 1,800 feet to the storage accumulator and the boilers (see Figure 3.3). The range of gas flow from the digester tanks is from 250 cfm to 700 cfm, on a daily basis. To handle this range and the future expansion, compressors with a range of 250 to 1,400 cfm were selected. The gas is not cleaned; it is fed to the boilers just as it is generated from the digesters. However, the gas compressor aftercoolers do remove a considerable quantity of moisture from the digester gas.

To maintain relatively constant gas flows and optimum digester operation, gas pressure transmitters are installed in the gas headers. These transmitters send a signal to change the speed of the DC, variable-speed motors at the compressors.

After compression, the gas is cooled and moisture separated off. Gas is carried to the boilers by a 12-inch pipe, suitably coated and protected to transport digester gas. The pipe was oversized to accommodate an anticipated 50 percent increase in digester capacity.

Initial studies of how to use the "excess" digester gas considered gas turbine gener-

ators, internal combustion engines, and water tube boilers. Boilers were selected for three reasons:

1) comparatively low capital cost and quick return on investment,
2) consistent plant demand and uses for low-pressure steam,
3) and low-pressure boilers would come on-line when existing high-pressure steam generators were being retired.

The new boilers are located in a building that had housed a sludge processing system. The boilers were sized to meet both the projected gas production levels and the plant steam requirements. Two boilers were purchased rather than one so that a back-up boiler would be available if needed. The extra boiler will be used when more gas is produced in the future.

The system is fully monitored and controlled to assure the safety of the operation. Faults in system operation cause the compressors to shut down automatically.

Energy and Economics

A significant amount of the natural gas requirements for deaerating boiler feed water, and plant heating and cooling are now met by using digester gas. As a result, the use of digester gas at the plant displaces enough natural gas to heat approximately 3,300 private homes, each burning 1,100 therms of gas every year.

When the first four digesters at the West-Southwest Works went into service in 1964, only enough gas was recovered to heat the digesters; the rest was flared off by waste gas burners. By 1978, when the gas recovery project was proposed, plant operations and the cost of energy had changed considerably. Flared gas at the West-Southwest Works represented 6,500 therms of energy lost every day. In 1978, the price of natural gas was $0.24 per therm, and the value of the gas the project proposed to save was $1,560 per day, or nearly $568,000 per year. By 1982, the cost of natural gas purchased by the Works had risen by $0.10 per therm, and the value of the digester gas had increased accordingly. Also, the volume of digester gas available for use in the boilers has increased to 10,000 therms per day because of an improved operating mode developed for the 12 digesters.

The total cost of the project was $830,000 with a payback on investment of less than two years. Operation and maintenance costs for the system are estimated to be $150,000 per year. Maintenance has been routine, and the bulk of the cost has been in wages for the boiler operators.

The West-Southwest Treatment Works project incorporated several elements which contributed to its cost-effectiveness.

1) Analysis, design, and construction of the project was carried out by Sanitary District employees.
2) The project was phased into long-range planning. Design and equipment decisions were made to allow for increased gas production and steam demand, and boilers were selected to replace others designated for retirement.
3) Equipment was selected that satisfied specific needs and was cost-effective. The boilers cost at least $1.5 million less than gas turbines.

Highlights and Current Status

Operation of the gas gathering and steam production system at the West-Southwest Works has been so successful that the Sanitary District has implemented a similar project at the District's John Egan Plant. Other municipal systems that use anaerobic sludge digestion and produce excess digester gas could benefit from the implementation of a gas recovery and use system. If the right conditions exist, plant managers can measure the amount of gas produced, determine its energy and economic values, and conduct a feasibility study to determine which options will yield the greatest benefits.

The amount of energy in the form of methane gas available from residential sewage can be estimated by using the following formula, if the number of people served is known.

$$\frac{\text{\# people}}{\text{day}} \times \frac{\text{650 Btu's}}{\text{person}} = \underline{\hspace{3cm}} \text{ Btu's per day}$$

Example: 1) If the sewage treatment plant serves 100,000 people per day, then:

$$\frac{\text{100,000 people}}{\text{day}} \times \frac{\text{650 Btu's}}{\text{person}} = \text{65,000,000 Btu's per day}$$

One pound of volatile solids yields about 12 ft³ of methane. So if the amount of volatile solids is known (typically 75 percent of total solids) methane production can be estimated. "Typical" wastewater has 230 mg/l of solids or 1,921 pounds/million gallons. Seventy-five percent of 1,921 is 1,440 pounds of volatile solids per million gallons. (An analysis of sewage at the plant will give a more realistic number for the average pounds of volatile solids per million gallons.)

Use the following formulas to estimate the energy value of the methane production potential:

(pounds of volatile solids per day) × 12 ft³/lb = ft³ methane per day

Example: 2)

(1,440 lb of volatile solids per day) × 12 ft³/lb = 17,280 ft³ per day

There are about 650 Btu's/ft³ of digester gas, so

(650 Btu per ft³ × 17,280 ft³ per day) = 11,232,000 Btu's per day

Cogeneration is an additional option. The conversion of methane to electricity is usually only 30 percent efficient, so if the digester gas is burned in an internal combustion engine, the electricity available can be calculated as follows:

Example: 3)

$$\frac{\text{11,232,000 Btu's per day}}{\text{3,414 kWh per Btu}} \times (.30) = \text{987 kWh per day}$$

Heat from the engine can usually be reclaimed at 30 to 65 percent efficiency, and this heat can be used to heat digesters or supply other demands for heat.

ESTIMATING METHANE PRODUCTION

Bode, Dave, "Cutting Costs With Digester Gas," **Diesel and Gas Turbine Progress**, February 1980.

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PRODUCING ELECTRICITY FROM EFFLUENT OUTFALL

North Andover, Massachusetts Treatment Plant

Until about 1870, water was the principal source of power for American industry. A large number of the early water "mills" were located in the Merrimack River Valley, the center of the early textile industry in the United States. A feasibility study, funded with a $9,324 grant, indicated that the Greater Lawrence Sanitary District in the Merrimack Valley can continue this tradition using a water turbine-generator to reclaim energy from the effluent water which is discharged from the plant to the river about 40 feet below.

In the 1840's, James B. Francis, working in the Merrimack River Valley, invented the highly efficient Francis Hydro Turbine. Modern versions of this turbine are produced to exacting specifications and usually require from 6 months to 2 years to produce and deliver.

Another hydroelectric option is available for less money that works with lower heads (vertical distance the water falls) and flow rates. Mass-produced pump/generator sets use the pump operating in reverse as a turbine coupled with a generator or alternator to produce electricity. They are generally only 65 to 85 percent efficient, but they cost less initially, are more readily available, and can be delivered relatively quickly.

TURBINE GENERATORS FOR SMALL SCALE APPLICATIONS

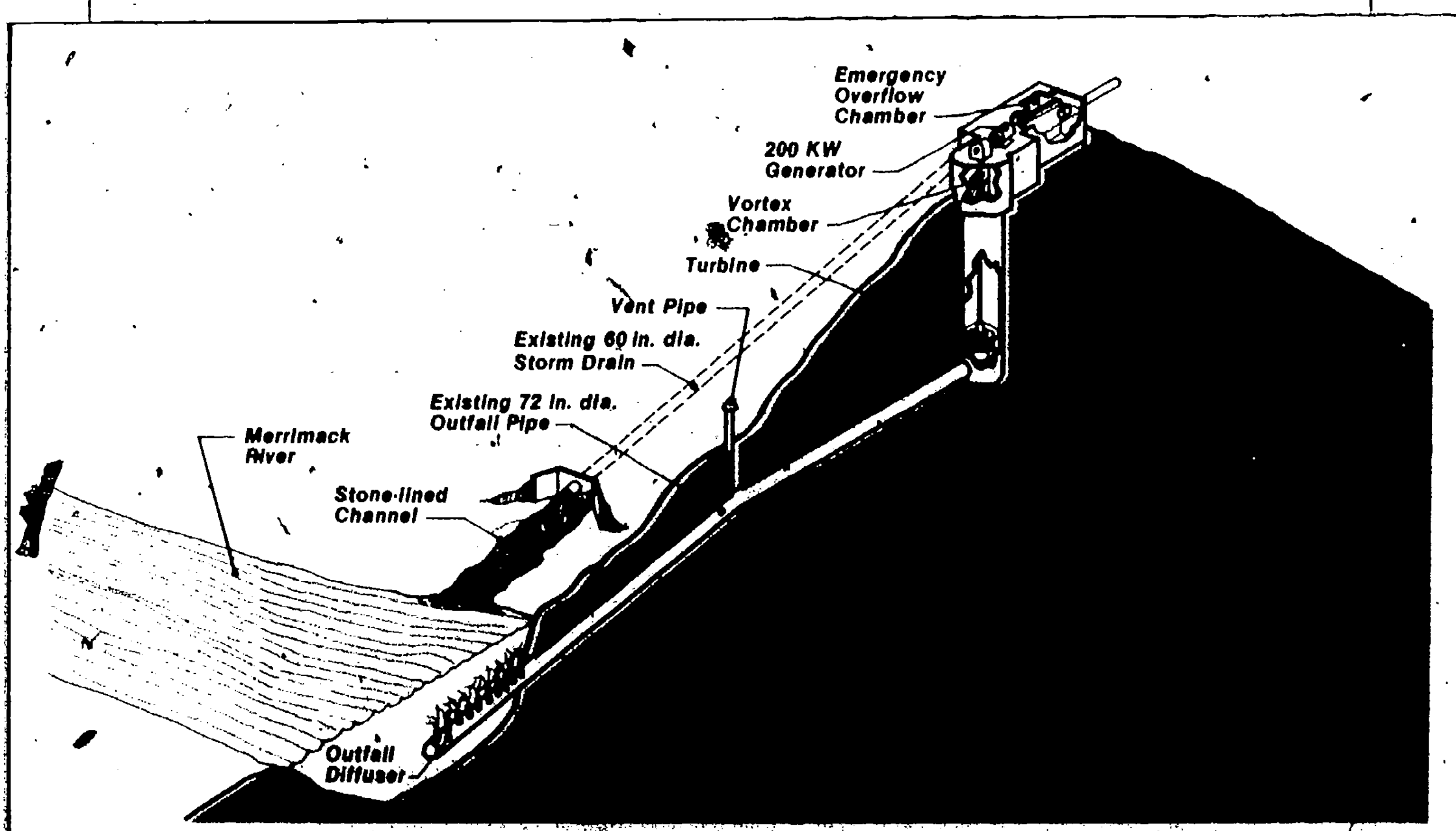
Technological Processes and Operation

As designed, an average 28 MGD of effluent water from the plant will flow down into a vortex chamber where a gated Francis turbine is mounted vertically. A shaft connects the turbine (via gears) to a horizontally-mounted, 200-kW induction generator. The 3-phase power will be fed into the plant's power grid at the plant water pump station.

After driving the turbine, the water will flow through a 72-inch outfall pipe and will be diffused through multiple openings into the river. An emergency overflow chamber can divert any excess water to a 60-inch storm drain and then into the river (see Figure 3.4).

Energy and Economics

The Greater Lawrence Sanitary District pays $0.068 per kWh for electricity. In the first year of operation the hydroelectric system is expected to generate 1 million kWh. By 1995, it is estimated that 2 million kWh per year will be generated. With constant growth in the plant loading rate, a total of about 19 million kWh of electricity will be produced by 1996.



It is estimated that the hydroelectric system will have an 8-year payback, assuming a 7 percent interest rate for borrowed money. Nearly $250,000 for project construction came from the Massachusetts Energy Office. Another $285,000 came from the Greater Lawrence Sanitary District.

Hydroelectric systems more than 80 years old are still producing power today, and the North Andover system could easily operate for 40 years. No operational data is available yet, but water power systems traditionally have low operation and maintenance costs. It is assumed that maintenance and operation will cost about $5,000 per year. The system will not require a full-time operator.

Highlights and Current Status

The Greater Lawrence Sanitary District has invested in an environmentally sound energy recovery system. The system is scheduled to become operational in April 1983. Instead of wasting energy and spending money, the hydroelectric system will use an existing situation to produce energy and save money.

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DOE Contract No.: DE-FG41-80R110409

In many plants, after the wastewater is treated it is discharged into a stream, river, lake, or the ocean. If the discharge water falls 8 feet or more, it may contain enough energy for practical hydroelectric production.

Many different turbine-generators are available, and the amount of electricity they can generate depends on three primary factors:

1) the flow rate in million gallons per day,
2) the vertical distance the water falls (head) in feet,
3) and the efficiency of the turbine-generator.

Discharge flow rates are measured routinely at most wastewater treatment plants. The distance the water falls is also easily determined. The efficiencies of turbine-generators, which range from 75 to 93 percent, and specific efficiency information can be obtained from manufacturers or found in hydroelectric literature. Variations in flow must also be taken into account when estimating turbine efficiencies. If variations are extreme, a flow equalization strategy may be required.

To estimate the amount of electrical energy per day that can be reclaimed from sewage effluent outfall, use the following formula:

(3.1426) × (MGD) × (Fall in Feet) × Efficiency = kWh per day

EXAMPLE: 3.1426 × 30 MGD × 40 ft × .8 = 3,017 kWh/day

Plants that seem to have the potential for producing energy with hydroelectric generation should also investigate the option of saving energy with cascade aeration.

ESTIMATING EFFLUENT DISCHARGE

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AN ANAEROBIC PRIMARY TREATMENT SYSTEM

Solar Aquasystems, Inc., at the San Elijo Water Pollution Control Facility, Cardiff-by-the Sea, California

With an $8,000 grant, Solar Aquasystems, Inc. designed and built a prototype Anaerobic AquaCell system. The system was tested from November 1978 to August 1979. While in operation, it demonstrated a two-cell primary treatment system for domestic wastewater that combined an upflow solids digestion process with a fixed-film anaerobic process.

Technological Processes and Operation

A prototype system, designed to approximate the surface-to-volume ratios of a full-scale system, was constructed at the San Elijo Water Pollution Control Facility, which serves Cardiff-by-the-Sea and Solana Beach, California. The pilot plant was housed in a greenhouse structure that provided passive solar heating. After an initial loading with sludge from the county's anaerobic digester, raw sewage that had been ground and screened was treated by the 3,000 gal/d pilot plant.

Treatment took place in two cells. Both cells had floating black synthetic rubber covers for digester gas collection, heat retention, and odor control. Sedimentation and sludge digestion occurred in the first cell which used upflow percolation (see Figure 3.5). At this stage, bacteria attached themselves to sludge particles and broke down organic compounds into smaller molecules. These bacteria are relatively resistant to toxins and environmental fluctuations, and they respond relatively quickly to variable loading rates.

After 6 hours of water treatment in the first cell, the effluent entered the second cell. Methane-producing bacteria in the second cell attached themselves to an array of hanging plastic sheets and webbing with a very high surface area. These provided a stable attachment area, accelerated the removal of suspended solids, and permitted coagulated solids to drop to the bottom where they were further reduced and stabilized. The bacteria produced methane gas and carbon dioxide while reducing BOD_5 levels and some SS. The water treatment time in Cell Two was 8 hours.

Methane-producing bacteria are vulnerable to drastic influent changes. In the AquaCell process, the first cell acted as a buffer for the second, reducing toxins and moderating the wastewater temperature.

One of the primary disadvantages of conventional, high-rate, anaerobic systems is that temperatures must be kept high (35°C) for effective digestion. The Aqua-

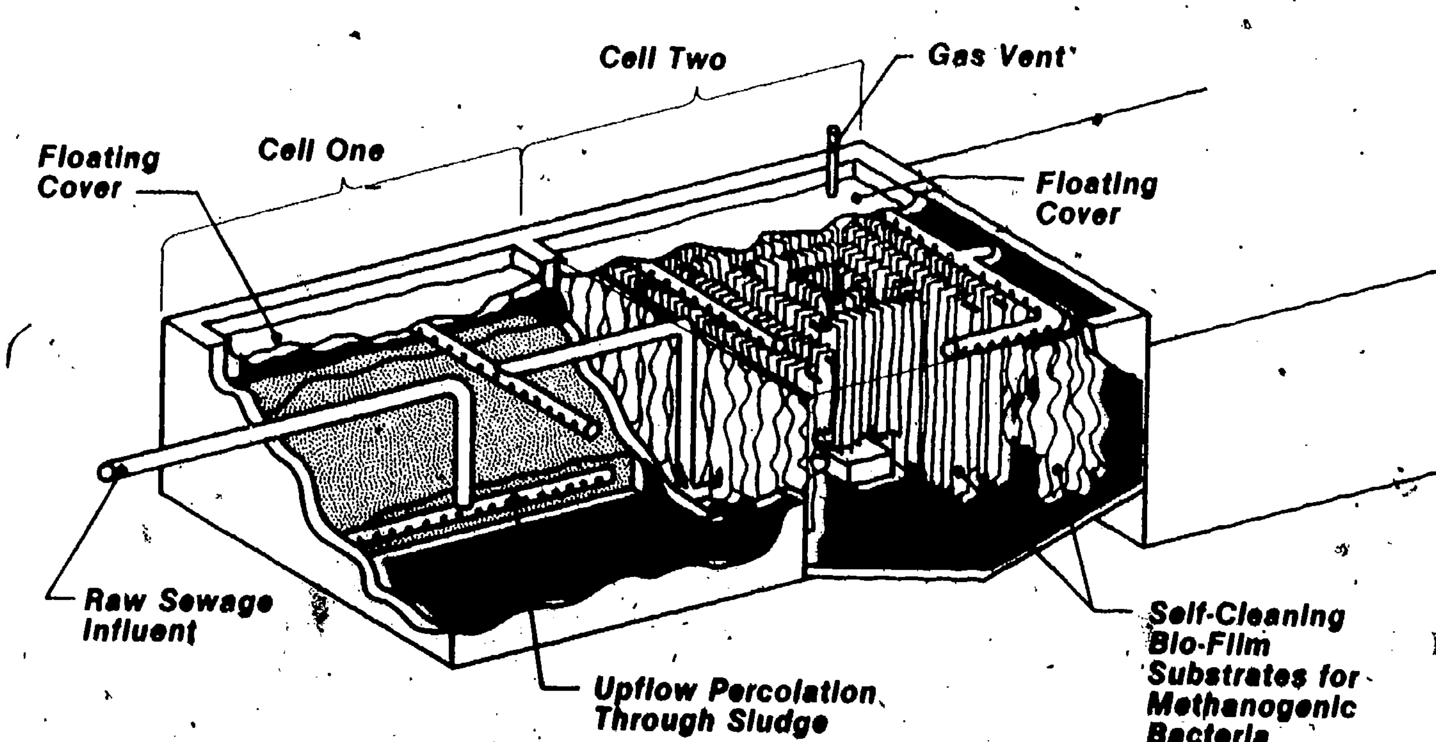

Figure 3.5 [illegible]

Cell operated from 18°C to 31°C with no apparent effect on removal efficiency related to temperature.

Project operators estimated that the solids content of sludge was reduced by approximately 85 percent during a 6-month period. Eighty-five percent is a significantly higher solids reduction rate than for conventional systems (see Table 3.2). The sludge produced during those 6 months was removed and dried on sand beds in only one week.

Over a 10-month test period, the Anaerobic AquaCell removed an average of 50 percent of BOD_5, and 88 percent of SS, with a 6-hour retention time in the first cell and 8 hours in the second cell. Coliform was reduced on an average of 96 percent (see Table 3.3).

Energy and Economics

The primary treatment process itself requires no energy. Energy is necessary for screening and grit removal and intermittent sludge pumping. However, because sludge continues to break down while it is retained in the cells, there is less sludge remaining to be pumped out. Because only intermittent pumping is necessary, less energy is used. In addition, the AquaCell system is an alternative to primary clarifiers and conventional anaerobic digesters, both of which require significant amounts of energy to operate.

Because there were problems with the seals on the floating covers of Cells One and Two, methane was not collected and production records were not obtained. However, gas containment should not be a problem if commercially produced enclosures are used at a full-scale plant. Based on process modeling and observations of the pilot plant, methane production should be substantial.

Capital costs for the AquaCell system are estimated to be approximately \$1 to \$2 per gallon of treatment capacity per day, depending on the size of the system. This is comparable to the cost of primary clarifiers. In 1982, this process was considered to be innovative and qualified for 85 percent federal assistance through the Construction Grants Program.

Maintenance and operating costs should be low because a separate sludge digestion

TYPE OF PROCESS	TREATMENT LEVEL		SEPARATE PROCESS REQUIRED FOR SLUDGE DIGESTION?	FREQUENCY OF SOLIDS REMOVAL	DRY SOLIDS PER DAY @ FLOW RATE OF 3785 m³/DAY (1 MGD), OR 10,000 PEOPLE
	Primary	Secondary			
SAS Anaerobic AquaCell	Yes	Yes*	No	Once/6-12 Months	170 kg (375 lb.)
Septic Tank	Yes	No	No	Once/1-2 Years	367.4 kg (810 lb.)
Imhoff Tank	Yes	No	No	Once/20-60 Days	313 kg (690 lb.)
Primary Sedimentation	Yes	No	Yes	Daily	340.2 kg (750 lb.)
Primary Sedimentation & Trickling Filter With Secondary Sedimentation	Yes	Yes	Yes	Daily	558 kg (1230 lb.)
Primary Sedimentation & Activated Sludge	Yes	Yes	Yes	Daily	635 kg (1400 lb.)
Activated Sludge (Package Plant)	Yes	Yes	No	Daily	1020.6 kg (2250 lb.)

*With longer retention times.

SOURCE: Alsten, C. and Stewart, W., **Performance Characteristics of a Covered Anaerobic Wastewater Lagoon Primary Treatment System**, NCAT ID # CA-78-032, Butte, MT, 1981

Parameter	Raw sewage influent	Anaerobic aquacell effluent*	% Removal anaerobic aquacell
BOD_5	218.4	109.0	50.0%
SS (mg/l)	247.9	27.9	88.7%
COD (mg/l)	518.0	142.0	72.6%
Turbidity (NTU)	205.0	103.4	49.6%
TOC (mg/l)	271.6	67.5	75.1%
pH (average means)	7.4	6.9	
Ammonia (mg/l)	40.9	34.0	16.9%
Coliform	5×10^7	2×10^6	96.0%

*6 hr retention time Cell 1; 8 hr retention time Cell 2

Table 3.3 Performance of AquaCell

process is not required and there are no chemical costs. Sludge can accumulate in the cells for relatively long periods of time which reduces handling and related costs. The system also eliminates the need for primary clarifiers and their associated costs. Because the system treats the wastewater (not just separating the sludge like clarifiers), pathogens are significantly reduced and disinfection costs would be lower. Operator training requirements are minimal, because the AquaCell system is simple to operate.

HIGHLIGHTS AND CURRENT STATUS

As this test project demonstrated, the two-stage anaerobic process for primary treatment has the following advantages:

1) Relatively little energy is required.
2) It operates effectively at moderate temperatures.
3) Methane gas is produced and could be collected.
4) It is stable and tolerant to variations in influent.
5) Maintenance and operating costs are low.
6) Capital costs are competitive with primary clarifiers.
7) It is simple and has no moving parts.

The anaerobic AquaCell system avoids the drawbacks common to anaerobic sludge digestion systems and anaerobic lagoons. It can gather the gas produced and control odors; open anaerobic lagoons cannot. The AquaCell is a medium-rate system and relatively stable. Consequently, it could operate for long periods with only intermittent checks and would not require special operator skills. High-rate, anaerobic sludge digestion systems are relatively sensitive and unstable, and require careful monitoring to maintain proper performance.

In 1978, the Solar Aquasystems project was one of the first to study the performance of a two-stage, anaerobic, fixed-film, primary treatment system at the pilot scale. Since then, numerous single-cell, upflow systems have been built. As of 1982, similar systems are eligible for 85 percent funding under EPA's Innovative and Alternative Technology Program, and EPA is funding additional research.

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DOE Contract No.: DE-FG03-78R901948

After primary treatment of the domestic wastewater in Cells One and Two, the effluent was treated in three more cells. Each of the additional cells contained high surface "bio-film" and "bio-web" substrates. Cell Three was facultative and used a small surface aerator and diffuse bubble aeration. Water hyacinths, duckweed and fish were used in the last two cells. The final three cells were funded by the Department of Interior and the Environmental Protection Agency.

If the products of aquaculture wastewater treatment are to be fully used, health hazards found in the sewage must be removed. The final three cells were used to remove heavy metals, PCB's, pesticides, pathogens, SS, BOD_5, ammonia, and other nitrogen and phosphate compounds.

The system was tested to see how well the series of five cells removed heavy metals and other toxic compounds. After measuring the amount of the compounds added to Cell One and the amount of these compounds in the effluent leaving Cell Five, the researchers reported extremely high removal efficiencies. Results indicated that removal rates with 4- or 5-day retention times were adequate to allow reuse of effluent for food production, if influent concentrations of toxics are within the range of domestic, rather than industrial types of sewage.

THREE ADDITIONAL CELLS IMPROVE SYSTEM PERFORMANCE

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VERMICOMPOSTING:

WORMS USED TO PROCESS SLUDGE Lufkin, Texas, Sewer Treatment Plant

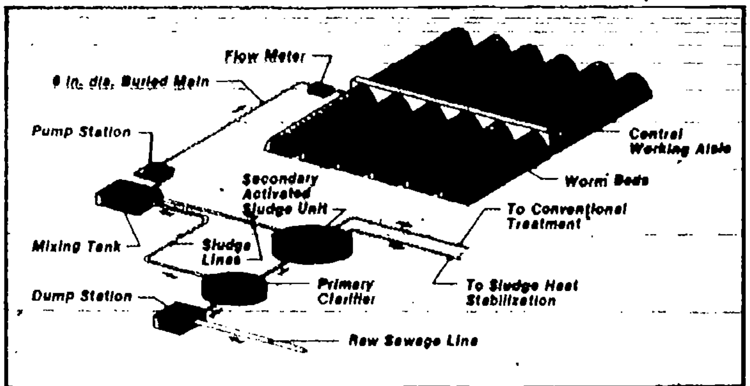

Figure 3.6 Lufkin Vermicomposting Facilities

Previous experimental work done in San Jose, California, and the practical use of sludge in the worm/fish bait industry in Texas, indicated that worms could be used to process sludge. Aware of this work, the City of Lufkin began construction of a 22,800 ft² vermicomposting unit at the city's Sewer Treatment Plant in 1979.

Earthworms transform large volumes of organic wastes to earthworm manure, called castings. This process is known as "vermicomposting." The conversion of wastes to castings increases the surface area enormously, and this accelerates drying and microbial activity. Castings crumble easily and no longer generate heat, so castings are a finished compost that will not burn plants.

Vermicomposting of wastes at any more than backyard scale has been practiced only since 1970. In that year, a facility in Hollands Landing, Canada, started vermicomposting sewage sludge, food-processing wastes, and manure. Worms have converted pulp and paper sludges to castings in Japan since 1971. The Japanese have expanded their efforts to include the processing of municipal sludge and other waste. In the United States, pioneering efforts in the vermicomposting of sewage sludge included demonstration projects in San Jose, California; Keysville, Maryland; Ridgefield, Washington; and Titusville, Florida. Vermicomposting is also being used in Holland, Italy, and the South Pacific.

Basic and applied research at the University of New York in Syracuse and Cornell University in Ithaca, New York, have developed greater fundamental knowledge of earthworm waste management systems. The objective of this work is to provide a scientific and engineering basis for the design and operation of vermicomposting systems.

VERMICOMPOSTING

TECHNOLOGICAL PROCESSES AND OPERATION

The worms live in 12 cells, each 20-ft wide by 95-ft long (see Figure 3.6). There are six cells on each side of a central working aisle. Each cell has a bed of aged sawdust, initially 6-inches deep, spread on polyethylene film on the ground. For each square foot of surface area, there is about one-half pound of earthworms (*Eisenia foetida*). Each cell is constructed of steel tubing arches covered by two layers of six-mil plastic (one black and one clear), filled with air from a blower.

The Lufkin treatment plant is a conventional 4.5 MGD facility with activated sludge secondary treatment. For the vermicomposting project, one part stabilized sludge from the primary clarifier and one part secondary activated sludge are mixed in a holding tank and pumped to the worm beds. The sludge mixture contains 3.5 to 4 percent solids and is piped from the holding and mixing tank and sprayed over the beds at a rate of .05 lb (dry)/day/ft². Treatment plant operators designed special constant-pressure valves to distribute the sludge. Each bed is covered by three sprayers controlled by an operator from the central aisle. The worms ingest and digest the sprayed sludge; this uses the water and stabilizes the sludge as it is converted to castings.

The worms are spray-fed sludge on an average of once a day for 3 to 5 minutes in the late afternoon. The beds are hosed down with additional water to keep them at the desirable 70 to 95 percent moisture content. The beds are also monitored for temperature and pH. The optimum bed temperature range is 60° to 75°F, and pH is kept at 6.4 to 6.9 with occasional applications of small amounts of lime. When a crust forms on top of the beds, usually at 1- to 3-month intervals, the top 2 inches of the beds are rototilled lightly. It takes about 20 minutes to till a 1,900 ft² bed. Beds are tilled when the worms are relatively deep, so losses are minimal. One person can maintain all 12 of the cells.

Worms are sensitive to changes in the weather and are inclined to crawl out of the beds during rainy periods or thunderstorms. Lights are turned on in the cells at these times to keep the worms from leaving. Normally, the cells are kept dark and well-ventilated.

Castings are toxic to the worms, and they must migrate or die if fresh bedding is not available. At approximately 6-month intervals, or when the casting exceed 50 to 70 percent of the bedding, the material from three 2-foot wide trenches is removed for the length of the beds. The trenches are

filled with aged sawdust, and the fresh bedding areas are watered and fed while the rest of the bed is left unmaintained. The worms migrate to the new material, and after about 2 weeks the rest of the old bedding is removed and replaced.

Energy and Economics

Due to the experimental nature of this project, the state Health Department does not allow Lufkin to sell either worms or castings. The castings are used by the Lufkin Parks and Recreation Department as a soil amendment-fertilizer and potting soil. The wholesale value of castings is about $30 per ton, but to date the Health Department restrictions still stand, and no commercial development has taken place.

Under good conditions, the worm population doubles every 2 to 3 months. Assuming a 25 percent recovery rate, about 10,000 lb of worms could be harvested every 6 months. At $1.50 per pound for live worms, the income potential is about $15,000 per year. As a protein source for fish or animal feed, worms are worth about $130 per ton.

Exclusive of potential income from castings and worms, vermicomposting is a promising sludge processing technology. Based on the Lufkin data, it is estimated that the cost of processing sludge is from $160 to $184 per dry ton, which is comparable to the costs of other treatment processes (see Table 3.4).

This process is quiet, requires negligible energy, produces "topsoil" and protein, and uses biological processes rather than energy and chemicals to process the sludge.

Sludge Disposal Method	$/Dry Ton
Incineration	$96 to 287
Composting	$84 to 239
Surface impoundments	Apprx. $30
Landfills	$88 to 271
Ocean dumping	$36 to 60
Ocean discharge	Apprx. $24
Landspreading	$48 to 251

Source:
Office of Water Program Operations, U.S. Environmental Protection Agency, **A Guide to Regulations and Guidance for the Utilization and Disposal of Municipal Sludge**, EPA-430/9-80-015, Washington DC, September 1980. (Adjusted for 1982 $.)

TABLE 3.4: COSTS OF SLUDGE DISPOSAL (1982 $)

Highlights and Current Status

Four of the twelve beds at Lufkin are fully operational. The other eight are now being reconditioned after suffering from delayed maintenance and ant predation.

Restrictions on the sale of worms and castings produced by the system have hampered commercialization, but the project has added substantially to the knowledge and practical information on vermicomposting at a relatively large scale.

The Lufkin vermicomposting effort has stayed in operation, despite setbacks, because of strong and continuing support from local officials. The project has also benefited from assistance from the U.S. Department of Energy and the State of Texas.

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CHAPTER FOUR:

LESSONS LEARNED AND FUTURE DIRECTIONS

The case studies featured in this publication, other projects conducted under the Department of Energy's Appropriate Technology Small Grants Program, and related work provide several valuable lessons for those concerned with municipal sewage collection and treatment.

Wastes are resources. Chicago uses digester gas to produce steam. In North Andover, the plant effluent stream is being harnessed to produce electricity. And at Lufkin, worms are processing sludge to produce a valuable soil amendment.

Conservation works and pays. On a national basis, approximately 20-25 percent of municipal wastewater treatment budgets is allocated for energy. As the case studies indicate, there are two basic ways to cut energy consumption and costs: audit and manage treatment processes effectively, and use the resources of the "wastes" and the treatment processes themselves. The Walterboro project demonstrates the value of energy audits and management, and the Chicago and North Andover projects use byproducts of the treatment process to help meet in-plant energy requirements.

Work with what you have. Major changes are not necessary to achieve results. Walterboro, North Andover, and Chicago all built on existing situations to improve the performance of their systems, and all three of these projects also recycled equipment and buildings as their treatment plants evolved.

Modify when time and money permit. Working with what you have applies to time and money as well as equipment and buildings. Sewage treatment is a major component of municipal budgets, and cost savings can be realized by incorporating improvements into long-range planning.

Use problems to explore options. No one likes to see problems crop up, but when they do, they often bring opportunities along with them. In each case cited in this publication, an existing problem was the motivation for change: high energy costs, non-compliance, inadequate capacity. As this publication also illustrates, there is a wide range of options available to help solve problems.

Sewage problems will not go away. Sewage collection and treatment is a persistent need and essential service in this country. It is a service taken for granted by most of the population, and in effect, this places additional responsibility on professionals who act on the public's behalf. Recent experiences and a broader understanding of environmental hazards, water resource cycles, and the increasing costs of all public services make it even more important to develop and operate the most effective and efficient sewage treatment systems possible.

Appropriate technologies can help provide answers. Appropriate technologies, applied to both conventional and alternative forms of sewage treatment, can help plant managers harvest the energy and nutrients of sewage. Viewing sewage as a resource rather than a liability can save energy and taxpayers' money.

APPENDIX A

SELECTED SEWAGE TREATMENT PROJECTS FROM THE DEPARTMENT OF ENERGY APPROPRIATE TECHNOLOGY SMALL GRANTS PROGRAM

Project type	Project grantee	Project scale
Algae and plant biomass used to treat wastewater converted to alcohol	City of Cayce, SC	Pilot-scale test system
An alternative on-site sewage system to conserve water	Soil-crete Solar Company, Navajo Dam, NM	Full-scale test system
Bacterial seeding used to save energy	Department of Public Works, Springfield, MA	Small-scale test system
Blue-green algae used to treat wastewater	Experimental Energy, Environment, Inc., Atlanta, GA	Small-scale test system
Conversion of sewage sludge to oil with hydropyrolysis	Patrick S. Kujawa, Vienna, Va	Feasibility study
Fish and bivalves used to remove suspended solids	Everett Sewer Department, Everett, WA	Small-scale test system
Methane digester for wastewater grown aquatic plants	Solar Aquasystems, Encinitas, CA	Small-scale test system
Methane produced from municipal refuse	North Country Recycling & Resource Recovery, Winthrop, NY	Pilot-scale test system
On-site vermicomposting used to convert commercial produce	Semple Street Food Co-op, Pittsburgh, PA	Full-scale test system
Owner-built compost toilet design	Farallones Institute Rural Center, Occidental, CA	Full-scale test system
Sequencing mesophilic and thermophilic anaerobic digesters	City of Atlanta, GA	Bench-scale test system
Sewage treatment effluent used as evaporative coolant for solid waste-fired generating plant	Valley City, ND	Feasibility study
Solar energy used to dry sludge	Jefferson Parish Dept. of Public Utilities, New Orleans, LA	Small-scale test system
Water hyacinths in solar greenhouses used to treat wastewater	City of San Marcos, TX	Pilot-scale test system

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